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CONTINUED INVESTIGATION OF
SOLID PROPULSION ECONOMICS

Cost-Effectiveness of Large Booster
Feasibility Demonstration and
Development Programs

Prepared for:

NATIONAL AERONAUTICS AND
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September 1967

Principal Investigator: John Baird

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**SRI Project MU-5139
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ABSTRACT

A 260 development and preflight rating test program was outlined. The experimental subscale and full scale test content of that program was outlined based on no prior 260 feasibility test demonstration program accomplishment. The estimated cost of the program was based on past experience.

The cost-effectiveness of the recently completed 260 feasibility test demonstration program, in relation to the 260 development and PFRT program, was based on a judgment of equivalence of feasibility program accomplishments to development program requirements.

The cost-effectiveness of the 260 feasibility test demonstration program was high. Eighty-three percent of the expenditures made at one of the two sources used for the feasibility effort was found to be effective as completion of the 260 development and PFRT program effort.

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INTRODUCTION AND SUMMARY

Solid propellant rocket propulsion technology was refined as a result of the significant effort expended to develop propulsion elements for weapon systems. The technology has matured as a result of continuing development efforts to meet the increasing demands of those systems for reliability, reproducibility, shelf or storage life, economy, performance, and environmental tolerance. The design capability, materials, processes with process controls, and facilities that were developed enabled the application of solid propellant technology to large propulsion units for manned launch vehicles. The effectiveness of that application was demonstrated on the Air Force Titan IIIC 120" diameter solid booster program where success in terms of program span time, cost, and propulsion system flight performance is unprecedented.

To evaluate the promise of reduced launch vehicle system costs and improved reliability through application of solid propulsion technology to large launch vehicles, NASA has completed several 260 application studies (Ref. 1) and a 260 feasibility test demonstration program. In this test program, three 260" diameter, short length, solid rocket motors were fired. The feasibility of applying solid propulsion technology to large launch vehicles is clearly indicated by the performance predictability and reproducibility demonstrated on the first 260 units produced.

Because of the success of the feasibility test demonstration program, this study was made to examine the economic benefits of the feasibility program to a formal follow-on development and PFRT program.

Objectives

The objectives of this study were to:

1. Design and estimate the costs of a 260 development and preflight rating test (PFRT) program.
2. Estimate the cost-effectiveness of the completed 260 feasibility test demonstration programs based on development program requirements.

METHOD

260 Development and PFRT Program Design Basis

A 260 development and PFRT program is outlined. This outline appears to be cautious in view of the test success of all large solid propulsion subsystems and, particularly, the success of the 260 feasibility test demonstrations. The 260 development and PFRT program outlined for this analysis is assumed to be initiated without a preceding feasibility test phase. Further--even considering the technical confidence in solid propulsion technology permitted by test demonstrations--because of the size of the test units and the size and cost of facilities, cost-effectiveness in project management decisions requires proof of design and process adequacy and small scale process practice in the actual facility prior to full scale production or testing. Therefore, the development and PFRT program includes component and subscale testing. The facility and equipment requirements are indicated.

Costs for the program are estimated, using data from industry where applicable. The test content of the 260 feasibility test demonstration programs is that reported by industry, and the costs for those program elements are based on experience. Cost estimates for new facilities and large items of handling equipment that would be required for the development and PFRT phase are made on the basis of the type of structure involved and its weight; estimates are based on selection of a concept that requires minimum development.

260 Feasibility Test Demonstration Program Cost-Effectiveness Basis

The feasibility program completed is analyzed to find its technical and economic value in completing the 260 development and PFRT program. Where the development and PFRT program requires a demonstration of component functional performance, design or analytical method adequacies, process controllability or the existence of facilities or equipment, the completed feasibility program is examined to determine if all or a portion of the demonstration has been completed. The value of existing facilities and equipment to the development and PFRT program is determined. The percentage of expenditures made on the feasibility programs, which directly replace funding nominally required for the 260 development and PFRT program, is calculated and is termed the cost effectiveness of the 260 feasibility test demonstration program. The method used is outlined in Table 1.

Table 1

260 FEASIBILITY COST-EFFECTIVENESS RELATIVE TO A
260 FL DEVELOPMENT AND PFRT PROGRAM

I Define 260 FL development and PFRT program based on:

Status of technology but with no prior 260" size effort

Develop and evaluate design, materials, and processes prior
to full scale effort

II Estimate 260 FL development and PFRT program costs

III Determine 260 feasibility test demonstration program accomplishments
equivalent to 260 FL development and PFRT program requirements

IV Work to complete 260 FL development and PFRT program equals:

260 FL development and PFRT minus Equivalent portion of feasibility
program requirements test demonstration program

V Feasibility test demonstration program (cost effectiveness of)
equals:

$$\frac{\text{Equivalent portion of feasibility test demonstration program}}{\text{Total feasibility program accomplishments}} \times 100\%$$

RESULTS

Estimated Costs of a 260 Development PFRT Program

The cost of the 260 development and PFRT program as defined by SRI totals \$132.1 million. Facility requirements, presuming one motor loading position for the program and including a loaded full length motor delivery capability, equal \$26.8 million. The cost of tooling and equipment for the program is estimated at \$11.4 million. The development items, which include the process and material characterization programs and subscale motors, cost \$10.2 million. The full length motor tests cost \$77.9 million, which includes items of hardware to provide vehicle stage functions. The total cost for program management and engineering is \$5.8 million.

The estimated costs are tabulated below (in millions of dollars):

Item	260 FL Development and PFRT Program Cost
Facilities	\$26.8
Tooling and equipment	11.4
Development items	10.2
260 FL motors	77.9
Management and engineering	5.8
Total	\$132.1

Total Expenditures on a 260 Feasibility Test Demonstration Program

The total expenditures made for the 260 feasibility test demonstration program were \$96.7 million. Of this total, Aerojet General Corporation (AGC) and Thiokol Chemical Corporation (TCC) spent \$20 million and \$12 million, respectively, for propellant production and motor loading facilities. Air Force and NASA program expenditures totaled \$64.7 million. The expenditures for program activities (excluding facilities) were approximately equal at AGC and TCC. Including expenditures made for facilities, the total expenditures at AGC were \$52.3 million, and the total expenditures at TCC were \$44.3 million. The actual expenditures made in the program may exceed the amounts noted by approximately 5 percent. This incremental amount reflects the value of special tooling items capitalized by the contractors during performance of work on the program. Table 2 summarizes the 260 feasibility program expenditures.

Table 2

260 FEASIBILITY PROGRAM EXPENDITURES
(Millions of Dollars)

Total NASA funds	\$35.0
Total Air Force funds	29.7
AGA facilities	20.0
TCC facilities	<u>12.0</u>
Total	\$96.7

Contractor Allocation

<u>AGC</u>	<u>TCC</u>
\$20.0	\$12.0
<u>32.3</u>	<u>32.3</u>
\$52.3	\$44.3

Cost-Effectiveness Determinations

The cost of equivalent effort performed in the feasibility program is computed on two bases. The value of the total feasibility program effort performed at both AGC and TCC toward completing the development and PFRT program is computed; also the cost of equivalent effort performed at AGC only is computed. Where the effort completed on the feasibility program by both contractors is considered, the value of that work toward completing the development and PFRT program equals \$45.2 million. Where a single source, AGC, only is considered, that value is \$43.2 million. The difference is totally in the value of tooling and equipment items which would be applicable to the development and PFRT program. Based on this analysis then, where both contractors are considered, \$45.2 million of the \$96.7 million total expenditure for the feasibility program constitutes work toward completing the 260 development and PFRT program. The funds required to complete a 260 full length development and PFRT program are \$86.9 million (\$132.1 - \$45.2). If the development and PFRT program had not been benefited by the feasibility program, the required funds would equal the total estimated value of the development and PFRT program or \$132.1 million. These figures are tabulated in Table 3. The details of the analysis are given in Section IV--Cost-Effectiveness Analysis.

Table 3

COST-EFFECTIVENESS OF THE 260 FEASIBILITY PROGRAM
IN TERMS OF ITS VALUE TO A FORMAL 260 FL DEVELOPMENT AND PFRT EFFORT
(Millions of Dollars)

Item	260 FL Development and PFRT Program Cost	Cost of Equi- valent Effort Performed in the Feasi- bility Program		Cost to Com- plete Formal Development and PFRT Program
		AGC and	AGC	
		TCC	Only	
Facilities	\$26.8	\$20.0	\$20.0	\$6.8
Tooling and equipment	11.4	5.0	3.0	6.4
Development items	10.2	7.2	7.2	3.0
260 FL motors	77.9	13.0	13.0	64.9
Management and engineering	5.8	0	0	5.8
Total	\$132.1	\$45.2	\$43.2	\$86.9

The cost-effectiveness determined on the basis of percentage of feasibility program expenditures which are directed applicable to the development and PFRT program is as follows: 47 percent of the \$96.7 million total expenditure is effective toward completing the 260 development and PFRT program; 82.6 percent of the \$52.3 million expended at AGC only is effective in completing the development and PFRT program. Table 4 summarizes the cost information developed by SRI for this analysis and indicates computation of cost-effectiveness as above.

Where both AGC and TCC's efforts on the feasibility program are considered, the value to the development and PFRT program is \$45.2 million; where AGC is considered only, the value is \$43.2 million. The difference between these values is found to be totally the result of residual usable tooling and equipment. Use of two sources for feasibility demonstration programs does not result in increased cost-effectiveness.

Where expenditures made at AGC only are considered, cost-effectiveness of 83 percent is high. A far lower benefit from such a program might be expected since the feasibility work could be performed with less formality, greater risk, lack of parallel approaches or hardware sources, use of boiler plate or breadboard hardware, and soft tooling. The cost-effectiveness of the program as a benefit to a follow-on development and PFRT program is more typical of a formal development program where at least 15 percent of the funds might be expended on approaches that require basic redirection or termination of parallel approaches found to be unnecessary. The high effectiveness of the feasibility program expenditures results from completed test demonstrations being equivalent to demonstrations that would be required in a formal development program.

Table 4

COST-EFFECTIVENESS DETERMINATIONS

- I Cost of 260 FL formal development and PFRT program and facilities if performed without a prior feasibility demonstration test program is estimated at \$132.1 million.
- II The total amount expended for the 260 feasibility program including facilities is \$96.7 million; excluding the facility cost, the NASA and Air Force program funds expended equal \$64.7 million.
- III Of the \$96.7 million total expenditure, \$45.2 million (47 percent) is effective in completing the formal development and PFRT program; of the \$64.7 million program expenditures, \$25.2 million (39 percent) is effective in completing the formal development and PFRT program.
- IV Excluding the expenditures made at one of the two sources used for the feasibility demonstration program, \$43.2 million (82.6 percent) of the \$52.3 million expended at AGC only is effective in completing the formal development and PFRT program.
- V Cost of conducting the 260 FL development and PFRT program as benefited by the 260 feasibility program expenditures is \$86.9 million.

Additional benefits have resulted from the 260 feasibility demonstration test program that cannot be quantified. The work characterizing ablative nozzle materials will benefit all programs using those materials for nozzles or vehicle applications. The work developing fabrication methods for the large motor case will benefit hardware programs using large, shell-type structures.

260 DEVELOPMENT AND PFRT PROGRAM DESIGN

To estimate the base cost, a development and PFRT program is defined considering the status of large solid propellant rocket technology to be that developed and demonstrated by all testing, excluding that performed as part of the 260 feasibility test demonstration program. The exclusion permits determining the interdependent cost-effectiveness of the feasibility program that has been completed.

The development and PFRT program definition is based on developing confidence in functional suitability through process and material characterization and design conservatism rather than on statistical significance in full scale testing. This approach is consistent with that practiced on programs concerned with developing large systems such as aircraft and NASA's large launch vehicles.

A requirement of the PFRT phase is facilitating and demonstrating the adequacy of a (propellant) loaded motor delivery system. Therefore, the last few tests of the PFRT series are handled in a manner that demonstrates the functioning of a delivery system. Using similar equipment, handling of the motor at vehicle assembly for flight is possible at launch areas similarly equipped. The development and PFRT motor configurations and test objectives are shown in Table 5.

Subscale and Component

Included in this test phase is the design and execution of experimental programs to develop or evaluate materials, manufacturing processes, and process controls. The developed materials and processes are also subjected to trial at a scale that permits applying the process in a manner similar to full scale.

Motor Case Material and Fabrication Process Evaluation

Motor case material is procured to preliminary specifications, and, after its response to manufacturing process operations are determined, procedures and test methods are developed/evaluated for acceptance of raw material and all subsequent operations. Experimental work includes consideration of process faults and repairs. The materials and processes that have been qualified in laboratory and bench scale tests are applied to a test article, permitting process operations similar to full scale and enabling destructive testing.

Table 5

TEST CONTENT - DEVELOPMENT PROGRAM

Subscale and Component		Preliminary process proof for first full scale Full scale grain and insulation design confirmation Full scale nozzle design confirmation Full scale ignition system design confirmation Full scale stage structure and systems design confirmation
Full Scale Unit		
1	Development 1	Manufacturing process and equipment trials Process/QC trials Components, logistics operations trials Tooling and facility trials Personnel training Test equipment trials Motor performance determination Hardware durability
2	Development 2	Manufacturing process development Process control development Tooling and facility development Hardware development Test equipment development Motor performance reproducibility
3	Development 3	Manufacturing process development Process control development Incorporates changes to configuration of grain insulation and other hot motor hardware indicated as necessary for durability performance or process reasons Incorporates functional items possible as a result of earlier tests such as movable nozzle Hardware durability and performance determination
4	Development 4	Manufacturing process development Process control development Incorporates all stage hardware sensitive to motor firing environment Hardware design freeze Process procedures freeze Confirmation of results of Unit 3
5	PFRT 1	Incorporates all stage hardware Confirm results of Units 3 and 4

Table 5 (concluded)

Full Scale Unit		
6	PFRT 2	Hardware-GSE interface and function trial Logistics equipment and operations trials Ground equipment and service operations development Personnel training Peripheral determination of age stability of motor Determine effect of logistics environment on motor performance and durability
7	PFRT 3	Logistics equipment and operations development Ground equipment and operations development Confirm results of Unit 6
8	PFRT 4	Confirm results of Units 6 and 7 at low end of operational temperature range
9	PFRT 5	Confirm results of Units 6, 7, and 8 at high end of operational temperature range

Propellant

The propellant raw materials are characterized, the propellant is formulated, and its process characteristics and cured properties are adjusted to meet requirements. The processes are tried using laboratory, pilot, and full scale processes. The casting and curing operations are tried using a motor of sufficient size to evaluate full scale motor processing methods.

Nozzle Ablative Surface

The raw materials and processes are evaluated at laboratory and small scale to establish performance parameters. The manufacturing processes are developed and evaluated using a nozzle size that permits applying processes similar to those for the full size nozzle.

Other

To scale up significantly materials application, processes, or components in the full size motor, the work necessary is similar to that discussed above. The route is generally from the laboratory to a large-sized subscale experiment. Initial testing at full scale is generally not practiced because, where uncertainties exist, the cost and hazard of the full scale experiment cannot be justified. Other elements of the large propulsion system that might be investigated in this manner include the materials and processes associated with the motor internal insulation, motor case destruct elements, thrust termination devices, flexible elements associated with a large movable nozzle, and gas generators and mechanisms for auxiliary power units.

Full Scale Testing

Unit 1

The basic objective of the first unit is applying the selected manufacturing processes that have been developed and evaluated only in the laboratory and at subscale. Data are acquired that enable the improvement of manufacturing processes, logistics, equipment, tooling, and facility. The first unit permits training of personnel and evaluating static test firing equipment. The static test firing tends to confirm design and analytical method and permits preliminary determination of motor component durability.

Unit 2

The second unit incorporates developments in manufacturing processes and controls, tooling, facility, and test equipment. Changes to the

design of the hardware will be of a minor nature unless dictated by test result of Unit 1. Basic design changes to the hardware are not considered probable--considering the status of the technology in general, the prior laboratory and subscale work completed, and the conservative design. The primary objective of the static test firing will be the determination of motor performance reproducibility.

Unit 3

The third unit incorporates functioning items such as a movable nozzle made possible by other full scale testing. Changes to processing or minor changes to the propellant grain or other motor components indicated as necessary for durability or performance reasons might be made. The manufacture of the third unit permits developing processes, tools and facility items. The changes are based on full scale determination of design and analytical method suitability and are made with a high degree of confidence. The static test firing yields motor hardware durability and performance information.

Unit 4

This unit incorporates all stage hardware sensitive to motor firing environment and is the prototype of the PFRT design. The major motor component design and manufacturing processes are frozen. The static test firing yields confirmation of the test performance of Unit 3.

Unit 5 - PFRT 1

The first PFRT unit incorporates all stage hardware that functions during motor firing with the exception of the forward skirt. The assembly and checkout and prefiring checkout will be accomplished using prototype ground service equipment. The static test firing of the motor will confirm the results of units 3 and 4 and will yield data on the operating environment and performance of accessories providing vehicle stage functions.

Unit 6 - PFRT 2

The second PFRT unit is the first unit where logistic equipment is tried. The trial also permits exposure of the motor to its logistic environment. After manufacture and assembly to its transport configuration, the motor is removed from the manufacturing facility and placed on a carrier. The time on the carrier will be in excess of the time in transport and hold prior to flight. The motor will be returned to static firing location, where assembly is completed, the motor is checked out, and static test fired. The static test firing will determine the effect of the logistic environment on motor performance and durability.

Unit 7 - PFRT 3

The third PFRT unit will be processed and handled in a manner similar to PFRT 2. The objective of the static test firing will be to confirm the results of Unit 6.

Unit 8 - PFRT 4

PFRT 4 will be conditioned and handled in a manner similar to PFRT 2. The activity provides operational practice and opportunities for training of user personnel. Static test firing will confirm results of units 6 and 7, except that the motor will be fired with the propellant grain conditioned to the low end of the operational temperature range.

Unit 9 - PFRT 5

This unit is the same as PFRT 4, except that the propellant grain will be conditioned at the high end of the operational temperature range prior to firing.

260 FEASIBILITY TEST DEMONSTRATION PROGRAM COST-EFFECTIVENESS

In this section, the feasibility program expenditures are analyzed to find applicability to the defined 260 FL development and PFRT program.

Facilities

The \$32 million expended to date for facilities consists of \$12 million for the propellant production and motor loading facility in Georgia (TCC) and \$20 million for the propellant production motor loading facility in Florida (AGC). Both facilities have been active and have demonstrated a capability of manufacturing propellants that meet the rate and control requirements for large motors. While the capability of both facilities is similar, the Florida facility is probably more adaptable as it has been operated more extensively and more recently. For these reasons, the higher cost facility is shown as more applicable to a new development and PFRT program. Since the development and PFRT program is presumed to be performed on a schedule that does not require more than one motor loading position, both facilities are not needed. Both facilities are, in fact, applicable to 260 programs; both motor loading positions could be equipped for delivery of units in a similar fashion.

Improvements and modifications to the propellant production and motor loading facility are estimated, on a cursory basis, to require \$2 million. These improvements will consist of rehabilitation and checkout of plant equipment after any downtime and construction of motor assembly and inert processing areas.

Neither the Florida facility nor the Georgia facility is equipped to deliver a propellant loaded motor from the cast and cure position to any carrier. To provide this function, the cost estimate for new facility items is made on the following basis: The delivery and transport system concept involves the use of a simple vertical lifting device located at the cast and cure position. In the delivery configuration, the motor is assembled with handling rings and the aft skirt. Assembly of the motor to the delivery configuration is made with the motor mounted vertically with the nozzle up. The motor is lifted vertically until trunnions on the forward handling ring can engage saddles on a motor rotation and transport dolly. The motor is lowered to the transport dolly in a straight vertical fall. The transport dolly rolls on eight rails to permit the straight vertical fall. The rails extend approximately one-half mile to a barge, which has been dry docked. The transport dolly rolls onto a matching eight-rail road in the special barge, which permits transport to use site where unloading and erection of the motor can be accomplished with similar equipment. The estimated cost for the 2,500 ton vertical

lift is \$1 million; one-half mile of eight-track road is \$1.5 million; two miles of canal, \$1.3 million; and the barge dock basin, \$1 million. The barge dock basin is assumed to consist of a submerged concrete slab and a bulk head against which the barge is secured for grounding during loading.

The total estimated facilities requirement for a 260 FL development and PFRT program is \$26.8 million where the estimating basis presumes no prior feasibility program. Where the expenditures made as part of the feasibility program are considered, the estimated requirement for new facility funding is \$6.8 million.

NASA funding was not directly involved in procuring the Georgia and Florida facilities. The facilities were designed, constructed, and financed by the industrial organizations involved. The facilities represent, however, industrial capability that has been, or will be, paid for largely with government funds. For this reason, cost-effectiveness of the facility investment has been indicated.

The total facilities requirements and the effect of the feasibility program expenditures are indicated in Table 6.

Table 6

260 FL Development and PFRT Program
FACILITIES REQUIREMENT AND EFFECT OF FEASIBILITY
DEMONSTRATION PROGRAM EXPENDITURES
(Millions of Dollars)

<u>Facilities</u>	<u>Estimated Funding Requirements for Development and PFRT Program</u>	<u>Expenditures Applicable to Development and PFRT Program</u>	<u>Funds Required To Complete De- velopment and PFRT Program</u>
Propellant produc- tion and motor proc- essing	\$20.0	\$20.0	\$
Improvements and mod- ifications	2.0		2.0
Loaded motor handling			
2,500-ton vertical lift	1.0		1.0
1/2-mile 8-rail road	1.5		1.5
2-mile canal	1.3		1.3
Barge dock basin	1.0		1.0
	<u>\$26.8</u>	<u>\$20.0</u>	<u>\$6.8</u>

Tooling and Equipment

The estimated cost of requirement tooling for the development and PFRT program, presuming no prior feasibility demonstration program, is \$11.4 million. This estimate is made from a perspective based on actual expenditures for the feasibility demonstration program, assuming hardware production rates consistent with a four-year development and PFRT span time. Single sources for hardware are assumed and a cost increase for some improvement in existent tooling is included. The estimated value of usable tools and equipment procured on the feasibility program is \$5 million. When this amount is subtracted from the total requirement of \$11.4 million, the cost to complete the 260 FL development and PFRT program is \$6.4 million.

The equipment items are the major pieces required for development and PFRT testing of the motor assembled with structural and functional stage hardware. These items consist of the special barge, which permits roll-on of the rotation and transport dolly carrying the motor and a major piece of the ground service equipment, the instrumentation van. The primary function of the barge and transport dolly is described under Facilities. The instrumentation van is the same as that used on the Air Force Titan III program, and the cost estimate is made using that perspective. The van interfaces with the stage through a single umbilical connector and is equipped to acquire and store data and to control and monitor all stage functions. The van is used for stage checkout and is assumed to be usable with suitable isolation during static firings.

In executing the feasibility program, two separate sources for all hardware fabrication and service were used. Because of the use of two sources, a large amount of soft or expendable special tooling was fabricated. Of the total expenditure for hardware, approximately 50% is shown as having adequate life and utility when applied to the development and PFRT program. Typical items of tooling acquired during the feasibility program that are considered applicable are listed below.

Handling Rings

The handling rings fabricated during the feasibility program could be used with modification in fabrication and shipment of full length empty cases. Their value is \$500,000.

Hydrotest and Aging Furnace

These facility-like, special tools are usable for the implied functions associated with case manufacturing. Their value is approximately \$1 million.

Miscellaneous

Other items of tooling considered to have adequate life consist of (1) internal and external staging used in motor case manufacturing and inert and propellant processing of the motor, (2) material handling containers and access tools, (3) propellant casting tooling and equipment, and (4) the items of special test equipment that interface with the motor and installed elements of the static firing data acquisition system. The value of \$5 million assigned as applicable to the development and PFRT program from the expenditures made on the feasibility program appears to be reasonable after examining the tooling and equipment items and their costs. This value is time dependent, however, as items considered applicable to the development and PFRT program will be modified and used on other programs or disposed of in accordance with established government procedures or will lose value as a result of corrosion.

The tooling and equipment requirements and the effect of feasibility program expenditures are shown in Table 7.

Table 7

260 FL Development and PFRT Program
TOOLING AND EQUIPMENT REQUIREMENTS AND EFFECT OF
FEASIBILITY DEMONSTRATION PROGRAM EXPENDITURES
(Millions of Dollars)

<u>Tooling and Equipment</u>	<u>Estimated Funding Re- quirement for Devel- opment and PFRT Program</u>	<u>Feasibility Program Expen- ditures Appli- cable to De- velopment and PFRT Program</u>	<u>Funds Re- quired to Complete Development and PFRT Program</u>
Motor case fabrication tool- ing	\$ 3.0	\$5.0	\$
Nozzle fabrication tooling	0.5		
Motor processing	2.5		
Special test equipment	1.2		
Special barge	1.4		
Motor rotation and transpor- tation dolly (2)	1.8		
Ground service equipment instrumentation van	1.0		
Total	\$11.4	\$5.0	\$6.4

Laboratory Component and Subscale Development

This category includes fabrication process characterizations, roll control system development, and the subscale motor program. Estimates for these separate items are based on experience from the feasibility program and estimates of labor and hardware content, assuming maximum use of available technology and hardware. The program elements listed for the 260 FL development and PFRT program presumes no prior feasibility test demonstration program.

To determine cost-effectiveness, the feasibility program expenditures considered applicable are only those estimated for the development and PFRT program and for the work that was actually completed during the feasibility program. This assignment of effort from the feasibility program to the development and PFRT program depends on several factors. In assigning applicable expenditures, no change is assumed in case material, propellant formulation or nozzle materials, and process method. It is expected, however, that in designing the full length motor attempts would be made to use materials and processes that improve function or reduce cost. The overall influence of such changes on this analysis is expected to be minor, as the cost of the program to characterize a new material and process should be recovered in fabrication costs of the hardware involved in the development and PFRT program (Ref. 2).

A subscale motor program is indicated at a cost of \$5 million. This estimate is based on the design manufacture and test firing of two 120" diameter motors. The primary objective (as defined in Table 5) is to complete trials of design methods, materials, fabrication processes, tooling, and procedures at an economically practical scale. Since this trial has been completed both in the TCC and AGC feasibility program efforts, the total cost for the effort is shown as applicable from the feasibility demonstration program.

The estimated total cost of the laboratory, component, and subscale development efforts for the development and PFRT program—assuming no prior feasibility effort—is \$10.2 million. The feasibility program accomplishment is equivalent to \$7.2 million, and the cost of the effort required to complete the development and PFRT effort is \$3 million. The 260 FL development and PFRT program cost breakdown in this category and the effectiveness of the feasibility program expenditures are shown in Table 8.

Table 8

260 FL Development and PFRT Program
LABORATORY, COMPONENT, AND SUBSCALE DEVELOPMENT AND EFFECT OF
FEASIBILITY DEMONSTRATION PROGRAM EXPENDITURES
(Millions of Dollars)

Laboratory, Component, and Subscale Development	Estimated Funding Re- quirement for Devel- opment and PFRT Program	Feasibility Program Expen- ditures Appli- cable to De- velopment and PFRT Program	Funds Re- quired to Complete Development and PFRT Program
Case materials and process characterization	\$ 0.9	\$0.9	\$
Propellant formulation; mate- rials and process characteri- zation	0.7	0.7	
Nozzle ablatives and case in- sulation materials and proc- ess characterization	0.6	0.6	
Igniter	0.3		0.3
Nozzle bearing and seal and mechanism	0.3		0.3
Auxiliary power unit	0.8		0.8
Roll control system	1.3		1.3
Instrumentation system	0.3		0.3
Subscale motor program	<u>5.0</u>	<u>5.0</u>	<u> </u>
Total	\$10.2	\$7.2	\$3.0

Full Scale Test Motors

Table 5 lists the objective of the fabrication and testing effort for each of the development and PFRT full size test motors. The first development units are tested to determine the loads that would have to be reacted by components located in, on, or near the motor. In the sequence of tests listed in Table 5, the third development unit will incorporate all changes to configuration and all motor components that function during the burn time. The fourth development unit is a PFRT prorotype; if its functional performance meets requirements, the PFRT design is frozen. The five PFRT units demonstrate reproducibility in performance, tolerance of the motor to the logistics portion of the flight environment, and suitability of logistic tools and equipment. The cost for the nine 260 FL development and PFRT units is \$77.9 million; the unit cost increases as the hardware is brought to the stage configuration. The applicable expenditures for hardware from the prior feasibility program are considered equivalent to the first two development units at a cost of \$13 million; the applicable

funds are shown on that basis. The justification for that assignment will be discussed below.

During the feasibility program, subscale tests were completed at 120" and 156" diameters and at smaller diameters involving two separate motor processing plants. The testing was successful. These results preliminarily indicate the suitability of critical manufacturing processes and the adequacy of design and analytic method. A preliminary indication of reproducibility resulted. The feasibility demonstration program completed three test firings of half length 260" diameter motors. The first two 260" diameter motors were the same design and provided a demonstration of adequacy of critical processes at full diameter scale and reproducibility. The third 260" short length motor firing was configured to provide data on the loads applied to internal motor surfaces at the nozzle entrance. This feasibility program testing represents an equivalence to the first two development units of the 260 FL development and PFRT program, which was based on no prior feasibility program. This equivalence exists because the first two full length development units provide data that permit refining the design of motor components and applying prototype movable nozzle configurations. The third 260 SL feasibility test firing involved a change in propellant burning rate leading to the next logical step in that series--the increase to full length and the testing of a movable nozzle. The third test unit of the 260 FL development and PFRT program is essentially the same. The prior testing required in that program provides essentially the same possibilities for development of experience and evaluation of manufacturing capability, confirmation of design adequacy, and load determination.

The equivalence of the feasibility program to the 260 FL development and PFRT program is shown in Table 9.

Table 9

260 FL Development and PFRT Program
FULL SCALE TEST CONTENT AND EFFECT OF
FEASIBILITY DEMONSTRATION PROGRAM EXPENDITURES
(Millions of Dollars)

Full Scale Motors	Estimated Funding Requirement for Development and PFRT Program	Expenditures Applicable to Development and PFRT Program	Funds Required To Complete Development and PFRT Program
Development 1	\$ 6.4	\$ 6.4	\$
Development 2	6.6	6.6	
Development 3	6.9		6.9
Development 4	9.0		9.0
Development 5 - PFRT 1	9.8		9.8
Development 6 - PFRT 2	9.8		9.8
Development 7 - PFRT 3	9.8		9.8
Development 8 - PFRT 4	9.8		9.8
Development 9 - PFRT 5	9.8		9.8
	<u>\$77.9</u>	<u>\$13.0</u>	<u>\$64.9</u>

Program Management and Engineering Labor

The development and PFRT program is assumed to be performed in a four-year time span and will involve for management and engineering an average of 35 people in professional classifications and an average of 7 people in support classifications. On this basis, the supervisory engineering and management labor cost is \$5.8 million.

It is probably reasonable to show a portion of the feasibility program expenditures as applicable to this cost category of the development and PFRT program on the following basis: The project engineering staff, which was experienced in management of the feasibility program, would be assigned a similar responsibility on the development and PFRT program. The applicable expenditures representing benefits from the feasibility program would be equal to the time lost in staffing and instructing the new group. No feasibility program expenditures are shown as a benefit to the 260 development and PFRT program since the effectiveness is critically time dependent.

SENSITIVITY ANALYSIS

The finding of this analysis--that 45 percent of the AGC and TCC feasibility program expenditures and 83 percent of the expenditures made on the AGC portion of the 260 feasibility test demonstration program are effective in partially completing a formal 260 FL development and PFRT program--can be adjusted by judgment or assumption. For example, it could be assumed that the first part of a formal development and PFRT effort would involve exactly that effort which was entailed in the feasibility program. The cost-effectiveness would then be 100 percent, but the cost of the 260 FL development and PFRT program would be higher by the amount of feasibility program expenditures shown to be noneffective. The estimated cost of the 260 FL development and PFRT program would include all costs for effort expended in the feasibility program at AGC and TCC; the effective expenditures would be higher, and the cost to complete the feasibility and development and PFRT programs would be the same. This attitude, while not totally illogical, would obscure considerations of cost-effectiveness in designing feasibility and development programs.

It is possible that using the cost of the first two full length development motors as the benefit of the feasibility program is high and that only the cost of half length motors should be used. In this case, the cost-effectiveness of the AGC portion of the feasibility program is reduced from 83 percent to 75 percent. It could be assumed that the feasibility test demonstration does not entirely replace the subscale effort required in the 260 FL development and PFRT program since a subscale motor should be processed and static fired to requalify the motor processing plant, which would result in another reduction in feasibility program cost-effectiveness. There are feasibility program benefits that are difficult to quantify but that are important to any development and PFRT program. The feasibility program provided information on the real calendar time spans necessary to fabricate a case, move it to a process location, and process it through loading of propellant. This experience, coupled with the demonstration of design adequacy, provides assurance of adherence to the schedule that might be worth \$.5 million a day to a vehicle development program at peak activity levels.

The cost-effectiveness of the feasibility program on the development and PFRT program of 45 percent for two contractors and 83 percent for one contractor is considered reasonable.

Appendix

FEASIBILITY PROGRAM DESIGN

Appendix

FEASIBILITY PROGRAM DESIGN

General conclusions regarding the design of feasibility programs for cost-effectiveness from a study of the 260 feasibility program are:

1. Where the cost-effectiveness determination method is based on providing the foundations for specific follow-on work, the cost-effectiveness of the feasibility program is zero if the technology or hardware shown to be feasible never are applied to that specific follow-on work. This conclusion refers to the method specified for determining cost-effectiveness only. All work expended to demonstrate feasibility is expected to benefit other programs. For example, during the 260 feasibility test demonstration program, basic work was done to characterize ablative materials for nozzles that will benefit all users. The work associated with the large, high-nickel steel motor cases will benefit hardware programs using large shell structures. At Sun Shipbuilding and Dry Dock Company, the close tolerance and closely controlled weld fabrication processes developed for the 260 cores have been applied in fabricating deep submersible hulls. However, any dollar value assigned to these benefits would be hard to justify.
2. The cost-effectiveness of feasibility programs is not improved by utilization of two sources for completing the demonstration. The technical value of the demonstration is not improved by duplication at two locations, and the cost for the demonstration at two locations will be approximately double that for the demonstration at one source.

This conclusion does not seem warranted in view of the 260 feasibility demonstration program history. If a single source had been used, it is possible that the effort would have shown the fabrication of the 260 case to be nonfeasible. To those who would acquaint themselves with the technical details, this conclusion would be rejected since one case fabrication effort did not make best use of the technology available at the outset (weld deposit toughness as a design parameter). Since feasibility is judged on the basis of the data considered and since it is not probable that many individuals will consider any data but those describing the basic test demonstration, the use of two sources for the 260 feasibility demonstration is viewed as wise. This consideration points to the fact that feasibility demonstration programs must be designed to provide data in a form that will be understandable by, and presentable and acceptable to, a group that must judge feasibility. The attitude and response of different groups may vary widely, as will be seen below.

At the start of the 260 feasibility program one group thought that the 260 feasibility was either already demonstrated based on prior test experience or that demonstration of feasibility was purely a design and analytical task. This group probably based its conclusions or reasonable extrapolations on experience with the larger units being tested at that time, such as the first stage Minuteman and the Air Force's 100" diameter program. This group was technically qualified and knowledgeable and, at considerable risk in both finance and corporate prestige, backed conclusions by constructing plants to be ready to produce the large units.

To demonstrate feasibility, another group probably thought that it was necessary at least to fabricate and proof test a motor case and to manufacture and cast the amount of propellant required in the large motor.

A third group thought that it was necessary to fabricate and test fire at least two motors at full diameter to prove feasibility, which was done successfully. Other groups feel that feasibility has not yet been demonstrated. One group claims (for probably other than purely technical reasons) that the concept is not feasible because the motor cannot be handled. The implication is that the feasibility program completed did not go far enough in the scope of the demonstration.

Still other groups exist that indicate both by action and inaction that 260 feasibility has not yet been demonstrated. Inadequate proof of feasibility is a good reason for the attitude since all other experience and design efforts demonstrate that solid propellant propulsion devices offer higher reliability and lower overall system cost when compared with liquid propellant stages. Lower cost and higher reliability are usually an unbeatable combination leading to immediate application.

It is possible that demonstrating technical, economic, political, and tactical feasibility is only complete when the concept or hardware is proven in its application.

When each of these feasibility categories is examined regarding the 260 program, some additional conclusions seem apparent.

Technical Feasibility

People who are only nominally familiar with, and interested in, this specialized propulsion area should agree that the 260 size test that has been completed proves the feasibility of the concept of large solid rockets. Further, the indicated high cost-effectiveness of the feasibility expenditures in relation to a formal development and PFRT program shows that the feasibility program was, in fact, a preliminary propulsion subsystem development effort where the nature of the hardware and demonstrations made in terms of motor performance and cost far exceed those conditions necessary to prove feasibility. It must be concluded that technical feasibility has been demonstrated, and that if feasibility is not felt to have been demonstrated the reasons are other than technical.

Economic Feasibility

Significant expenditures have been made to study the application of large solid propulsion subsystems to launch vehicles. The studies have provided a preliminary definition of launch vehicle systems and the system costs. The applications are generally found to be advantageous and result in lower overall system costs. For example, the studies completed by the Douglas Aircraft Company indicate that a vehicle using a full length 260 first stage and an S-IVB second stage develops a system cost equal to the S-IB vehicle consisting of an S-IB first stage with an S-IVB second stage, except that the 260 S-IVB combination has three times the payload capability. The system operational cost utilizing the solid propellant booster is obviously one-third that of the S-IB vehicle in terms of cost per pound of payload in orbit. The finding of Douglas is considered significant since the study was performed using some costing information based on experience with large liquid stages, which is not particularly applicable or advantageous in evaluating a solid propellant boost stage. The finding may not be accepted generally since it is only based on analysis and was performed by a contractor with a vested interest. Other Saturn uprating studies have been completed by contractors for NASA involving boost assist and zero stage concepts using solid propulsion devices. These studies indicate economic advantages as a result of utilization of solid propellant propulsion devices but are also purely analytical and performed by contractors with vested interests and thus may not be accepted for these reasons.

The evolution of the military launch vehicles is a significant demonstration involving the entire propulsion industry as well as industries specializing in vehicle design, system design, and implementation. During that evolution and the change from liquid to solid propellant propulsion, the decisions made involved obsoleting facilities, system expendable hardware, and accepted concepts which were expensive. The fact that the decisions were made and implemented is not a study result; the action taken has been effective in increasing the military effectiveness of those systems while also producing a significant reduction in system cost.

The solid propulsion application study results, reinforced by experience in the application of solid propellant propulsion devices, clearly demonstrate economic feasibility. These results also reinforce the proof of technical feasibility made during the 260 feasibility demonstration program.

Political Feasibility

Political considerations are usually so far ranging and sequential in nature that they defy effective analysis. Congressional action regarding the NASA budget and the 260 program appears to be at least tolerant, if not favorable, and the demand for reducing costs is clear.

Tactical Feasibility

Tactical feasibility involves considerations of interdependent systems. Tactical feasibility is considered to have been demonstrated where analysis indicates overall (national) technical and economic advantages for the application. As examples of the range in complexity of the considerations, tactical feasibility would be demonstrated if a new requirement were generated that overtaxed existing capability in terms of payload capacity, vehicle production rate, facility limitations, and vehicle performance characteristics. The new requirement then would justify, by itself, the procurement of the new launch vehicle system. Considerations such as obsolescence, the phasing in of new subsystems to existing systems, would not be necessary. As an example of a more complex analysis leading to demonstration of tactical feasibility, the substitution of the 260 S-IVB vehicle for the Air Force's Titan III vehicle should be considered. In this analysis, all elements of the system would have to be considered from the payload to the facilities and logistics of launch location. A simple substitution of a 260 solid propellant stage for the S-IB stage is probably equally complex. An analysis leading to determination of tactical feasibility would require consideration of hardware obsolescence, reassignment of personnel, redesign of payloads to utilize the greater capacity, modifications to launch facilities, and impact on facilities and staff used to process other hardware.

On the basis of a simple consideration, the existence of a payload requiring a new launch vehicle where application of the 260 motor is particularly suitable, the tactical feasibility is not indicated. On the basis of the replacement of a propulsion subsystem in an operational or developmental system, tactical feasibility is uncertain since the analysis is not known to have been completed or attempted.

Recommendations

It is recommended that the analysis suggested above under Tactical Feasibility be completed. The determination of tactical feasibility is necessary to derive all possible benefits from the expenditures made for the 260 feasibility test demonstration.

REFERENCES

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2. "Large Solid Rocket Motor Case Material," Stanford Research Institute, January 1967